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(54) **Title:** CONTRAST-INCREASING PROJECTION SCREEN

(57) **Abstract**

(57) Abstract: The invention relates to a projection screen for representing static or animated images with the aid of one or several monochromatic laser light sources. Said projection screen is provided with a coating that reflects in a spectrally selective manner and a structured lacquer layer made of a hardened lacquer or a structured film made from a holographic master as a layer reflecting in a spatially selective manner in order to increase spatial selectivity.

For an explanation of the two-letter codes and other abbreviations, see the explanatory notes ("Guidance Notes on Codes and Abbreviations") at the beginning of each regular issue of the PCT Gazette.

Contrast-increasing Project Projection screen

The invention relates to a contrast-increasing projection screen for representing static or animated images by means of front projection through a narrow-band light source, such as one or more monochromatic light sources.

To be able to view projected images that are influenced as little as possible by interfering light, such as daylight or artificial room illumination, the reflection capacity of the projection screen should be low for the entire wavelength range of visible light, with the exception of those wavelengths that correspond to the radiation of the light source or light sources. For this reason, projection screens having a highly wavelength-selective reflection behavior are desirable for the direct front projection, especially of color images, using laser light sources or other more or less narrow-band light sources for multiple primary valences (for example, red, green, blue [RGB], such as LCD projection or CRT projection). This means that the reflection capacity of the projection screen should be as high as possible for those wavelengths that correspond to the primary valences used for projection, and as low as possible for other wavelengths, such as from ambient light.

In the context of the invention, reflection refers to the entire light intensity re-diffused or reflected by the projection screen, as it relates to the incoming light intensity.

In addition, the reflection of the projection screen should exhibit a selectable solid angle characteristic, wherein reflection occurs within a defined angle of radiation range, so that no light or only very little light is diffusely reflected in/from the (those) solid angle range(s) in which there is no viewer. Ideally, reflection should occur within an angle range of ± 40°, as measured horizontally from the normal on the projection screen, either to the left or right. As a result of the solid angle characteristic, a mirroring reflection is avoided and, instead, a diffuse reflection is achieved. In addition, the contrast is further increased relative to a Lambert projector.

To enable clear perception of the static or animated images on a projection screen, even in daylight, and without interference from daylight or other ambient light, the projection screen should have a spectrally and spatially selective reflection capacity.

Various proposals have already been made to simultaneously improve both the spectral and spatial selectivity of projection screen reflection.

In DE 197 47 597, for example, a projection screen is described in which spectral selectivity for monochromatic light, such as laser light, is accomplished with a multilayer system comprising layers of dielectric materials that are alternately highly and poorly refracting. As a result of this multilayer system, which acts as an interference filter, reflectivity is increased for the wavelengths of monochromatic laser light and is reduced outside the wavelength range of the projection light. To adjust the angle characteristic, pigments are provided in a separate lacquer layer on the projection screen.

DE 199 01 970 describes a spectrally selective reflecting projection screen for front projection with narrow-band, especially monochromatic, light, such as that generated by lasers, in which spectral selectivity is achieved with a coating of cholesteric polymers. In this case, to adjust the angle characteristic, the surface of the substrate to which the coating is applied is structured.

It has been shown, however, that when pigments are used to adjust the angle characteristic, the desired diffuse reactivity is achieved, whereas the particles produce a high degree of diffusion. As a result of this high degree of diffusion, light, which must first pass through this diffusing layer before it can penetrate to the spectrally selective coating, is already diffusely reflected in a spectrally non-selective manner in the diffusion layer, resulting

in the spectral selectivity of the projection screen being reduced or even destroyed.

If adjustment of the angle characteristic is achieved by structuring the surface of the substrate, the spectrally selective reflecting coating can essentially be applied to the structured surface, so that the structuring is transferred to the coating. Alternatively, the spectrally selective reflecting coating can first be applied to the smooth substrate, followed by application of the structured layer. This leads to the problem, in combination with interference filters, for example, that when coating is applied to a structured substrate, spectral selectivity suffers, because the peak positions of the wavelengths in the spectrum change and the substrate reflects more highly, as discussed in greater detail below in connection with Figure 2.

When the sequence is reversed, i.e., when the spectrally selective reflecting coating is first applied to the smooth substrate, a diffusing surface must be applied to the coating system. This is normally done by mechanically shaping the filter layer, which results in it being subjected to stress and possibly destroyed.

Thus, a need existed for a method of adjusting the solid angle characteristic of spectrally selective reflecting projection screens without encountering the problems mentioned above. In addition, the adjustment was to be capable of being performed easily and was to allow for an overall improvement in the spatially selective reflectivity of projection screens.

The object of the invention is solved by a contrast-increasing projection screen that contains a substrate and a spectrally selective reflecting coating, wherein the projection screen comprises at least one spatially reflecting coating, wherein the spatially reflecting coating is selected from a coating made of a hardened lacquer or a structured holographic film.

The invention also relates to the use of hardenable lacquers and structured holographic films to form such spatially reflecting coatings.

Any known spectrally selective reflecting coating can be used for the projection screen according to the invention, such as that described in the previously mentioned German patent application DE 197 47 597 A1, in international application WO 98/36320, and in German patent DE 199 01 970 C2, to which express reference is made in this context and which are incorporated in full into the present invention.

According to the invention, the spatially selective reflection is achieved by a coating having a structured surface, which consists of hardenable lacquer, or a structured holographic film, in which the surface and/or its volume has been structured and/or modified using holographic processes known in the art.

Structured holographic films are known in the art are already used, for example, by the POC Company in combination with a spectrally non-selective filter as a contrast-increasing projection screen (LORS). The increase in contrast achieved in this process, however, is insufficient, because it only result from the exclusive diffuse reflection of light from a defined solid angle range.

When the lacquer is used, the structuring occurring during the hardening of such lacquer layers is accomplished by polymerization and cross-linking of the input materials used, wherein shrinking processes occur that result in micro-folding of the surface. This micro-folding produces the desired structuring on the surface of the lacquer layer.

Suitable processes and materials for structured lacquer layers that can be used in accordance with the invention are described, in principle, in German patent application DE 198 43 510 A1. This application provides a very general description of a process for producing

decorative and functional surfaces on rigid or flexible substrates, but makes no reference to concrete applications. The processes and materials described therein can, in principal, also be applied to the production of the structured lacquer layer used in accordance with the invention.

The lacquers that can be used in the present invention are preferably electron beam- or UV-hardenable paint and lacquer layers. In principle, these paint or lacquer layer are obtained by applying initial mixtures of polymerizable or cross-linkable monomers and oligomers, with or without a photo-initiator, to a suitable substrate, in a conventional manner, and then hardening them by means of suitable irradiation. The extent of micro-folding and, therefore, the appearance of the structuring varies as a factor of the monomer/oligomer system used, coating thickness, UV wavelength, nature of the substrate, and coating technique. Thus, by simple variation of the aforementioned parameters, structuring can be adjusted in a targeted manner, depending on requirements.

Suitable lacquers and/or lacquer system are described at length in DE 198 42 510 A1.

Examples of suitable initial materials are acrylates, epoxies, vinyl ether, non-substituted and substituted styrenes, and mixtures thereof. These materials can be present in suitable solvents. In this process, the acrylates preferably have a functionality of 2 or more.

The hardening of these materials is normally accomplished by irradiation with monochromatic UV light at a wavelength suitable for the respective system. Preferably, the wavelength of the monochromatic UV light used for hardening is such that the UV light is still capable of directly forming polymer radicals for polymerization and cross-linking, lies within the UV absorption range of the lacquer component, and allows for hardening using a reasonable photon dose. In principle, all wavelengths capable of achieving hardening in the irradiated zone of the lacquer layer can be used to produce

the micro-folding, provided they correspond to the absorption spectrums of the lacquer components.

Examples of commercially available irradiating devices suitable for the present invention is [sic] an excimer UV laser, which emits monochromatic UV light at 172 nm and 222 nm, such as that obtainable from Heraeus Noblelight. An argon excimer laser with a wavelength of 126 nm is also suitable.

Because air absorbs short-wave UV radiation, producing ozone, the irradiation for hardening and folding the lacquer layer should preferably take place in an inert atmosphere.

It has been shown that the depth of photon penetration into the lacquer layer decreases as the wavelength decreases, so that finer structuring is achieved. Thus, a fine, invisible micro-folding is generally achieved with wavelengths of less than 200 nm, whereas larger, visible structures are achieved with longer wavelengths. It has also been shown that with radiation having a longer wavelength (222 nm), the peak-valley ratio of surface roughness and waviness increases with increasing lacquer layer thickness to a greater extent than with radiation having a short wavelength (172 nm).

According to a preferred embodiment, urethane diacrylate is used as a lack component, preferably together with a flexible reactive dilution agent.

Fine, low luster structures can be obtained with such flexible systems.

An irradiation device such as that mentioned earlier can be used for hardening.

To produce the structured lacquer layer, the initial components can be present in pure form, diluted with organic solvents, or as an aqueous dispersion. The initial components can be mixtures of radiation-polymerizable monomers/oligomers and liquid or dissolved, non-radiation chemically polymerizable polymers. For processing purposes, it has

proven to be advantageous when the viscosity of the initial components is less than 10,000 mPas at the time of exposure.

In principle, higher viscosity initial materials can also be used, although supporting measures are generally necessary. For example, higher viscosity acrylates can be structured with thermal support.

Systems with the composition described above are subject to shrinkage that is advantageous in terms of micro-folding, and possess the necessary UV reactivity.

The thickness of the lacquer layer is selected from within a range normally used for projection screens. The thickness of the lacquer layer used in accordance with the invention is preferably within a range of 5 to 15 μm.

However, it is understood that, in principle, lacquer layers can also be used for the present invention in which hardening is achieved by other mechanisms than irradiation with electron beams or UV light, as long as a suitable structuring of the surface occurs, such as by irradiation using different wavelengths or heat, etc.

In the case of structured holographic films, their function results from a surface relief that is reproduced by a holographically fabricated master. In this type of production, the most complete control possible over the structuring of the light-diffusing surface is especially advantageous. The completely random, non-periodic structures obtainable in this process can also be defined as randomly placed micro-lenses. The function of the films is not wavelength-dependent, and is equally effective with white, monochromatic as well as coherent and incoherent light. The random structure of the structured holographic films to be used in accordance with the invention destroy [sic] unwanted Moire effects and color diffraction. The incident light can be precisely controlled within highly defined ranges.

As a result, the diffusely reflected light can be limited to a solid angle range, so that the light yield can be optimized.

Vertically and horizontally variable solid angle ranges can be selected with the structured holographic film. This is especially advantageous for projection screens, because areas in which there are no viewers, such as the ceiling area, can be faded out and, furthermore, because rooms in which projection screens are used are commonly wider than they are tall.

To explain the invention in greater detail, exemplary embodiments are described below on the basis of the figures.

Figure 1 shows two embodiments of the projection screen according to the invention, with varying placement of the spatially selective reflecting coating.

Figure 2 shows a comparison between the optical output of a projection screen according to the invention, with a planar substrate, and that of a projection screen with a conventionally structured substrate.

Figure 3 shows a depiction of the angle-dependency of the reflection of a projection screen

according to the invention, with a lacquer layer structured to differing degrees of fineness.

Figure 4 shows a schematic depiction of the development of a spectrally selective, reflecting coating with a genetic algorithm, and

Figure 5 shows a diagram of the spectral progression of a projection screen obtained in accordance with the method shown in Figure 4.

As shown in the two embodiments an and b in **Figure 1**, the spatially selective reflecting coating 1 used in accordance with the invention can be placed at random, and can be located above (Figure 1a) or below (Figure 1b) the spectrally selective coating 2. In the depiction shown in the figure, it is located directly below the spectrally selective coating 2, while the individual layers are disposed on a substrate 3.

Whereas the structured lacquer layer/film, which acts as a spatially selective reflecting coating 1, provides for diffusion of the light projected onto the projection screen, illustrated here by arrows 4, 5, 6 and 7, spectral selectivity is achieved as a result of the coating 2.

According to another embodiment of the present invention, the structured holographic film can be used as a substrate. In this case, the spectrally selective reflecting coating 2 is applied to the smooth rear surface of the film.

In reference to Figure 1a, this means that the substrate 3 depicted there is eliminated. If, in addition, a multilayer system, such as an RGB filter, is used as a spectrally selective reflecting coating 2, the structure must be adjusted accordingly by performing the coating sequence during production inversely to the coating sequence on a separate substrate, as shown in Figure 1a, for example, and by taking the modified incident medium into account, which is now no longer air, but rather the structured holographic film.

An advantage of the projection screen according to the invention is that spatial selectivity is achieved by means of a thing, flexible, structured film or foil whose diffusing properties can be very finely adjusted during the course of production.

Another advantage, which is especially evident in a structure in accordance with Figure 1a, in which the structured lacquer layer/film is applied to the spectrally selective coating 2, is that as a result of the structuring of the surface, as provided in accordance with the invention, the initially applied spectrally selective coating 2 is not subject to any mechanical effects that could damage or even destroy it.

When the structured holographic film is used, the structure per se has already been generated prior to coating, thus avoiding the potential destruction of the filter by subsequent stamping. This is also advantageous because coating can be performed on a smooth surface (rear surface of the film and/or the substrate). Examples of materials

are glass or plastic. The substrate can be transparent or non-transparent. In the case of a transparent substrate 3, the projection screen can be used, for example, for projection onto transparent glass or plastic surfaces, such as windowpanes, as a head-up display, or the like. In the case of a non-transparent substrate 3, the substrate can be highly absorbent, by tinting it black, for example, so that it exhibits minimal diffuse reflection for all wavelengths of visible light. The substrate can be made of a flexible or rigid material. An example of a flexible substrate is a plastic film. When a structured holographic film is used for the spatially selective reflecting coating 1, it can also be used directly as a substrate. In this case, a transparent structured holographic film should be selected.

If the spatially selective reflecting coating 1 shown in Figure 1a is applied to the spectrally selective coating 2, a clear lacquer and/or a transparent film is selected.

If, in contrast, the spatially selective reflecting coating 1 is applied between the substrate 3 and the spectrally selective coating 2, any transparent or non-transparent material which is more or less permeable to light can be used. In this case, for example, the lacquer layer can be tinted with suitable dyes and/or pigments. Thus, for example, in place of the non-transparent substrate mentioned above, a suitably absorbent lacquer layer can be applied to an inherently transparent substrate.

In the case of the use of a structured lacquer layer, it was also observed that the addition of pigments promotes the development of micro-folding. Thus, to promote micro-folding, materials acting as nuclei for the development of micro-folding can be present in the lacquer layer.

As explained earlier, any spectrally selective reflecting coating known in the art can be used for the projection screen according to the invention.

For example, the spectrally selective coating 2 can be formed from one or more cholesteric polymer layers, such as those described in DE 199 01 970 C2. In this process, spectral selectivity is achieved on the basis of the properties of cholesteric polymers which, as a single layer, are capable of reflecting circularly polarized light with a specific orientation (i.e., either right or left circular), thereby each reflecting 50% of the non-polarized light in a specific wavelength band $\Delta \lambda$. To achieve optimal reflectivity, the projection screen should exhibit at least two cholesteric polymer layers that are enantiomeric relative to one another, together with suitable selectivity for this wavelength. Because cholesteric enantiomers reflect opposite circularly polarized light, both the right circular and left circular rotating portion of the non-polarized light is reflected in the respective wavelength band.

For this reason, a projection screen specially suited for RGB radiation should contain at least six layers of cholesteric polymers, wherein pairs of adjacent layers are enantiomeric relative to one another and reflect blue, red or green light, so that, overall, a reflection of close to 100% can be achieved for all RGB wavelengths.

The spectrally selective coating 2 can be constructed of a multilayer coating system comprising at least two dielectric materials with different refractive indexes. The coating materials, of which there are least two, are alternately applied to the substrate, so that low-refracting and high-refracting layers are alternately disposed on the substrate. The respective layer thicknesses of the high-refracting or low-refracting layers in a system can be identical or different. For example, one or more periods of at least one high-refracting layer have a first layer thickness and a low-refracting layer having a second layer thickness can be present. This is referred to as a periodic arrangement.

The thicknesses of the high-refracting and the low-refracting layer can also vary; this is referred to as an aperiodic arrangement.

Examples of suitable dielectric materials for the aforementioned coating 2 comprising layers of low-refracting and high-refracting materials are the oxides or nitrides of silicon, aluminum, titanium, bismuth, zirconium, cerium, hafnium, niobium, scandium, magnesium, tin, zinc, yttrium, and indium. Preferred examples of low-refracting materials are SiO_2 and $MgSS_2$ and, in particular, Al_2O_3.

Preferred examples of high-refracting materials are tantalum oxide, titanium oxide and niobium oxide, as well as Si_3N_4.

Examples of preferred combinations of high-refracting and low-refracting materials are silicon dioxide as a low-refracting material and titanium dioxide in the rutile phase and/or in the anastase phase as high-refracting material, as well as the combination SiO_2/Si_3N_4 and, in particular, Al_2O_3/Si_3N_4.

Another example of a suitable material is the mixed system $Si_{1-x-y}O_xN_y$.

Such coatings comprising a multilayer coating system consisting of a sequence of alternately high-refracting and low-refracting, dielectric materials act as an interference filter, with which the wavelengths of the projection light are selectively reflected.

As an alternative to the implementation of an interference filter by means of a multilayer coating system in the form of high-refracting and low-refracting layers, a filter system having a continuously and periodically modulated refractive index across the filter thickness can be used as a spectrally selective coating 2 – a so-called Rugate filter.

The $Si_{1-x-y}O_xN_y$ mixed system mentioned above, for example, can be used to produce such a filter having a refractive index modulated across the layer thickness; in this case, the refractive index is adjusted by varying the nitride concentration.

Other mixed systems comprising a low-refracting and a high-refracting component, such as mixed systems selected from among SiO_2/TiO_2,

SiO_2/Ta_2O_5 and SiO_2/Nb_2O_5, can also be used. In this case, the refractive index is adjusted relative to the mass ratio of the components.

Commonly known co-sputter processes or CVD processes, for example, can be used to produce such spectrally selective coatings 2 on the basis of mixed systems.

Methods of producing the multilayer coating systems from dielectric materials are known in the art and, for example, described in DE 197 47 597 A1 and WO 98/36320. Examples of suitable coating processes are vacuum coating processes, such as magnetron sputtering and electron beam evaporation.

It was found that by reducing the difference in the refractive indexes, the angle dependency or such a coating system comprising low-refracting and high-refracting layers can be reduced. For example, angle dependency can be reduced by replacing the low-refracting material with a material having a higher refractive index. Thus, angle dependency and, therefore, the displacement of the peaks of the primary valences in the spectrum, is lower for an Al_2O_3/Si_3N_4 coating system than for an SiO_2/Si_3N_4 system. In this case, the low-refracting material SiO_2 is replaced with Al_2O_3, which has a higher refractive index.

In Figure 2, the optical outputs of spectrally selective coatings on a planar substrate and on a structured substrate are compared. In this instance, a dielectric multilayer system, as described above, was selected as a spectrally selective reflecting coating.

The comparison illustrates that the spectrally measured reflection of a projection screen according to the invention, as shown in Figure 1b, in which the spectrally selective reflecting coating 2 is deposited onto a planar substrate 3, is significantly higher the spectrally measured reflection of a projection screen where the coating 2 is applied to a structured substrate. This result clarifies the advantage of a coating on planar substrates followed by structuring or, as is possible with the structured holographic film, structuring on the side of the substrate facing away from the coating 2, as provided in accordance with the invention.

The method according to the invention can be used to adjust the diffusion behavior of a given projection screen by simple modification of the structuring of the lacquer layer or the structured holographic film, which form the spatially selective reflecting coating 1, so that the angle characteristics of the projection screen can be varied as needed.

Figure 3 shows the angle dependency of the reflection of projection screens, according to the invention, having a lacquer layer as a spatially reflecting coating 1, which differ in terms of angle characteristics. Here, the differences in terms of angle characteristics result from the use of lacquers with structures of varying fineness.

According to the invention, therefore, it is not only possible to achieve higher reflections, because planar substrates can be used. In addition, the angle characteristics of a projection screen can be adjusted, depending on requirements, by simple modification of the structuring of the lacquer layer and/or the film.

For this reason, as already explained in connection with Figure 1, the spectrally selective reflecting coating 2 can essentially be located above or below the substrate 3. Preferably, however, the geometric distance between the selectively reflecting coating 2 and the diffusing surface, i.e., the structure of the lacquer layer and/or the film, should be

as small as possible, which, for example, can be achieved with the smallest possible thickness of the lacquer layer and/or film.

If the diffusing surface and the spectrally selective reflecting coating 2 are too far apart, the sharpness of the image suffers and "double or ghost images" can develop.

In a preferred embodiment of the invention, such as that shown in Figure 1a, the structured lacquer layer is applied to the spectrally selective reflecting coating 2. In this case, the optical properties of the lacquer can also be taken into account when configuring the coating 2, so as to achieve optimization of the optical properties of the projection screen. By adjusting the chemical composition of the lacquer, for example, the refractive index of the lacquer can be adjusted to conform to the properties of the coating, and a so-called index adjustment can be achieved.

According to another embodiment, an antireflex coating 8 to remove mirror images can also be provided on the spatially reflecting coating 1 of an embodiment such as that shown in Figure 1a, in which the spatially selective reflecting coating 2 is located below the spatially reflecting coating 1. By providing an antireflex coating 8, intrinsic reflections potentially occurring on the surface of the coating 1, which can amount to approx. 4%, can be reduced to less than 1%.

In principle, conventional antireflex coatings can be used for this purpose. An example of a suitable antireflex coating is a layer system comprising TiO_2(11 nm)-SiO_2(40 nm)-TiO_2(110 nm)-SiO_2(85 nm). Antireflex coatings can, for example, be applied by means of a vacuum coating process (vacuum evaporation or sputtering) or deposited onto the surface of the projection screen using a wet chemical coating process (sol-gel process). Examples of suitable processes are magnetron sputtering and electron beam evaporation.

According to another preferred embodiment, the spatially selective reflecting projection screen according to the invention contains a spectrally selective reflecting coating 2, which is optimized in the sense that, in addition to providing the highest possible contrast, it also provides the best compromise among minimal layer thickness, a small number of the coating materials used, and a small number of individual layers.

Conventional layer systems for coatings, such as those described above, are produced by selecting the materials for the individual layers, the respective layer thickness, and the number of layer thicknesses while specifying a defined, discrete target spectrum.

Although the layer systems obtained in this manner provide a contrast suitable for practical use, they are not optimized in terms of additional attributes of a projection screen considered desirable for achieving the most optimal image possible.

However, layer systems are desirable that not only provide improved contrast, but also provide this improved contrast together with the smallest possible thickness of the overall layer system and the individual layers, as well as the smallest possible number of layers.

Furthermore, the projection screen should also allow for suppression or at least the greatest possible suppression of the so-called color flop effect. Color flop is defined as a change in the viewer's perception of color, which is caused by a change in the viewing angle. This is attributable to the angle-dependent reflection-transmission behavior of interference filters.

Depending on requirements, additional marginal conditions can be specified for the projection screen. For example, a means of improving color neutrality consists in the projection screen having the most uniform peak heights possible for the primary valences. Color neutrality means that, for example, projected white does in fact appear as a white and does not, for example, contain a tinge of red. Conversely, it was found, according to the invention, that suitable color neutrality can be achieved by matching the intensities of the primary valences of the respective projector with the respective projection screen. In this process, the white adjustment to

achieve color neutrality is done directly in the projector itself, and not on the projection screen. In this case, significantly higher contrast values can be achieved with identical layer thicknesses than with a projection screen featuring identical peak heights for the primary valences. The cause of this is the possibility of reducing green reflection, to which the human eye is highly sensitive.

The spectral sensitivity of the human eye can also be taken into account to produce an optimal image impression for the viewer.

The layer system, particularly when there is a predetermined number of layers, should exhibit an optimal profile in terms of the properties mentioned above.

To obtain a spatially selective reflecting projection screen having the properties mentioned above, it is preferable to use a spectrally selective reflecting coating for the projection screen according to the invention which is obtained by applying an evaluation process based on color metrics, instead of the conventional [method of] optimization against a fixed, predetermined reflection spectrum.

To this end, colorimetric evaluation is combined with an optimization algorithm, which does not require a predetermined initial design as input for optimization, and which already reproduces the essential elements of the color spectrum. A so-called genetic algorithm, which is known in the art and described, for example, in Heistermann, J., "Genetic Algorithms – Theory and Practice of Evolutionary Optimization," B.G. Teubner, 1994, and in Goldberg, D.E., "Genetic Algorithms in Search, Optimization, and Machine Learning," Addison-Wesley, Reading, 1989, has proven to be especially suitable for this purpose. By combining this algorithm, which is robust and easy to implement, with colorimetric evaluation methods, it can be used for the optimization of optical coatings.

In the following, the mode of operation of the genetic algorithm for optimization of spectrally selective reflecting coatings for projection screens is described in greater detail, with reference to the flow chart in Figure 4.

The mode of operation of the genetic algorithm is based on evolution and natural recombination strategies. The underlying concept is that from among a number of individuals who, together, form a generation, essentially only those individuals can be selected to generate a new generation who have the best characteristics relative to their environment. In the present case, an individual is defined as a layer system, together with its layer thicknesses and material properties. The parameters of the layer system, such as layer thicknesses and materials, are referred to as genes. The algorithm initially generates a population of individuals by randomly assigning materials and layer thicknesses (referred to as "static population" in Figure 4). These individuals are then evaluated and sorted according to quality. This is followed by a loop comprising the steps recombination, mutation, evaluation and selection (selection of the better individuals, i.e., layers), in which poor layers are, for the most part, discarded. By repeating the loop, an improvement is achieved in the average quality of the population and in the absolute quality of the individual, until an optimum is reached. The advantage of the genetic algorithm over standard hill-climbing algorithms lies in its parallelism and in the inclusion of currently less favorable individuals who, through further recombination in subsequent generations, can reveal new search areas in the fitness function. This is important for a global search.

Genetic algorithms exist in a wide variety of variations which, in essence, can be used in the present procedure.

To produce the projection screens used in accordance with the invention, the evaluation and, therefore, optimization is completed on the basis of colorimetric considerations. Because the evaluation is done on the basis of colorimetrics, it is not necessary to specify a discrete target spectrum.

The contrast, in this case, results from

$$k = \frac{1}{3} \frac{R_{Blau} + R_{Grün} + R_{Rot}}{Y} \tag{1}$$

where Y is the standard color value and, therefore, a measure for the brightness of the reflection spectrum. k indicates the contrast achieved by the projection screen, for primary valences of the corresponding wavelengths, relative to ambient light.

To execute the algorithm, a modified formula (1) can be used to evaluate the contrast. The most significant change consists in replacing the sum by a product:

$$k = \frac{1}{Y^n} \left(\prod_{i=B,G,R} R_i \right) + \frac{C}{R\sigma} \tag{2}$$

where σ_R is the standard deviation of the reflection capacity and *C* is an empirical factor. N is generally set to 3 for three primary valences. By selecting other values, this exponent can also be used to balance reflected brightness against resulting contrast.

To minimize or eliminate the color flop effect, the layer system should be designed so that the change in reflected intensities caused by modifying the viewer angle is identical for all wavelengths of the projected light. As a basis for evaluation by the algorithm, the spectrums of an individual (layer system) are calculated for various viewing angles and the changes in reflected intensities are compared for the wavelengths of the primary valences, wherein standard deviations of these values are applied.

If necessary, the adjustment of the color neutrality of the image can also be achieved by means of white adjustment, wherein the intensity of the light of one of the wavelengths of the primary valences (red, green, blue) reflected by the projection screen is matched against the

intensity of the monochromatic light of the corresponding wavelength, as emitted by the projector.

Based on the procedure described above, and with the aid of the genetic algorithm, an evaluation of a layer system can be performed that does not require a fixed, predetermined value for a discrete reflection spectrum, and that increases the contrast while simultaneously suppressing the color flop.

As a result of the described combination of a genetic algorithm with an evaluation based on colorimetrics, spectrally selective reflecting coatings are obtained that contain a significantly improved contrast along with an optimally reduced overall layer thickness and number of individual layers.

This process can be used, for example, to obtain coatings having a contrast of at least 2.5 and an overall layer thickness of less than 4.5 μm.

Figure 5 schematically depicts the spectral progression of a spectrally selective reflecting coating obtained in accordance with the genetic algorithm described above.

This coating comprises a layer system consisting of low-refracting and high-refracting dielectric materials. The coating consists of twelve individual layers, with SiO_2 as the low-refracting material (n = 1.46) and Si_3N_4 as the high-refracting material (n = 2.05), which have been deposited onto a glass substrate.

The layer structure, progressing upward from the glass substrate, is as follows:
Glass
Si_3N_4 239 nm, SiO_2 210 nm,
Si_3N_4 324 nm, SiO_2 319 nm,
Si_3N_4 435 nm, SiO_2 197 nm,
Si_3N_4 22 nm, SiO_2 241 nm,
Si_3N_4 72 nm, SiO_2 372 nm,
Si_3N_4 249 nm, SiO_2 35 nm.
This coating provides a contrast improvement k of 3.55.

A detailed description of the development of spectrally selective coatings by means of genetic algorithm, especially of layer systems comprising low-refracting and high-refracting dielectric materials, is provided in Ch. Rickers, M. Vergöhl, C.-P. Klages in: "Design and manufacture of spectrally selective reflecting coatings for the use [sic] with laser display projection screens," Applied Optics, Volume 41, No. 16, June 2002, to the full content of which reference is made for the purposes of the present invention.

It should be noted that especially high reflection in the range of laser wavelengths is not as important in terms of increasing contrast as the lowest possible reflection in the spectral range outside of it [the range of laser wavelengths].

In the genetic algorithm, this effect can be taken into account by influencing the weighting used to suppress the substrate. This is done by varying the exponent of Y accordingly in equation (2).

It was also found that a reduction in the peak width of the wavelengths of the laser light in the spectrum is only of limited value in terms of increasing contrast, because this results in a substantial decrease in the reflected intensity during viewing at a different angle, i.e., an increase in angle dependency.

Claims

1. Contrast-increasing projection screen, which contains a substrate (3) and a spectrally selective reflecting coating (2),
characterized in that
the projection screen comprises at least one spatially reflecting coating (1), wherein the spatially reflecting coating (1) is selected from between a coating formed from a hardenable lacquer and a structured holographic film.

2. Contrast-increasing projection screen according to Claim 1,
characterized in that
the spatially reflecting coating (1) is a hardened coating comprising at least one material selected from among acrylates, epoxies, vinyl ether, non-substituted or substituted styrenes.

3. Contrast-increasing projection screen according to Claim 2,
characterized in that
the spatially reflecting coating (1) is a hardened coating based on acrylates.

4. Contrast-increasing projection screen according to one of the preceding claims,
characterized in that
the spatially reflecting coating (1) consists of UV-hardenable material.

5. Contrast-increasing projection screen according to one of the preceding claims,
characterized in that
the spectrally selective reflecting coating (2) is a layer system comprising two or more layers, wherein at least one combination of a low-refracting and high-refracting material is used as layer material.

6. Contrast-increasing projection screen according to one of Claims 1 to 4, **characterized in that** the spectrally selective coating (2) is a layer system comprising at least two layers of a cholesteric polymer.

7. Contrast-increasing projection screen according to one of the preceding Claims 1 to 4, **characterized in that** the spectrally selective coating (2) is a filter system having a refractive index continuously and periodically modulated across the filter thickness.

8. Contrast-increasing projection screen according to one of the preceding claims, **characterized in that** the spectrally selective reflecting coating (2) is a combination of cholesteric polymer layers and dielectric layers.

9. Contrast-increasing projection screen according to one of the preceding claims, **characterized in that** the spectrally selective reflecting coating (2) exhibits a contrast k of at least 2.5 and an overall layer thickness of less than 4.5 μm.

10. Contrast-increasing projection screen according to one of the preceding claims, **characterized in that** the spectrally selective reflecting coating (2) is a coating system selected from between SiO_2/Si_3N_4 and Al_2O_3/Si_3N_4.

11. Contrast-increasing projection screen according to one of Claims 1 to 10, **characterized in that** the material for the substrate (3) is selected from between transparent and a non-transparent material.

12. Contrast-increasing projection screen according to Claim 11,
characterized in that
the material for the substrate (3) is selected from between a flexible and rigid material.

13. Contrast-increasing projection screen according to one of the preceding claims,
characterized in that
the substrate (3) is planar.

14. Contrast-increasing projection screen according to one of the preceding claims,
characterized in that
the structured holographic film acts as substrate.

15. Use of a hardenable lacquer layer as a spatially selective reflecting coating (1) for a projection screen.

16. Use according to Claim 15,
characterized in that
the hardenable lacquer layer consists of an electron beam or UV-hardenable lacquer.

17. Use according to one of Claims 15 to 16,
characterized in that
the lacquer layer consists of a hardenable lacquer based on a material selected from among acrylates, epoxies, vinyl ether, non-substituted and substituted styrenes.

18. Use according to Claim 17,
characterized in that
the hardenable lacquer layer consists of an acrylate-based material.

19. Use according to one of Claims 16 to 18,
characterized in that
the lacquer layer consists of a lacquer hardenable with UV light.

20. Use of a structured holographic film as a spatially reflecting coating (1) for a projection screen having a spectrally selective reflecting coating (2).

21. Use of a structured holographic film as a substrate for a projection screen having a spectrally selective reflecting coating (2).

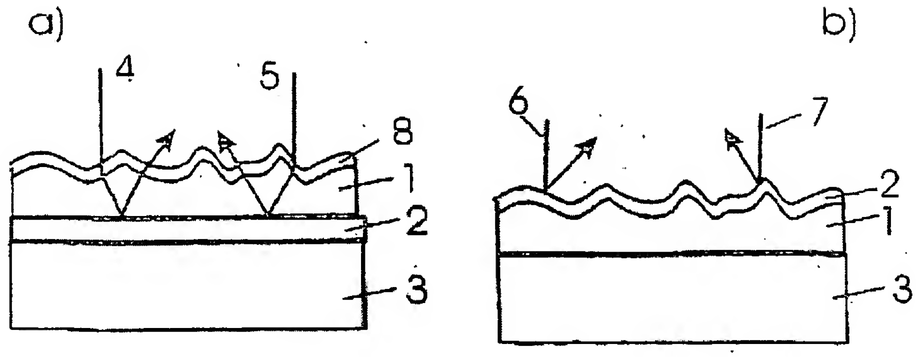


Fig. 1

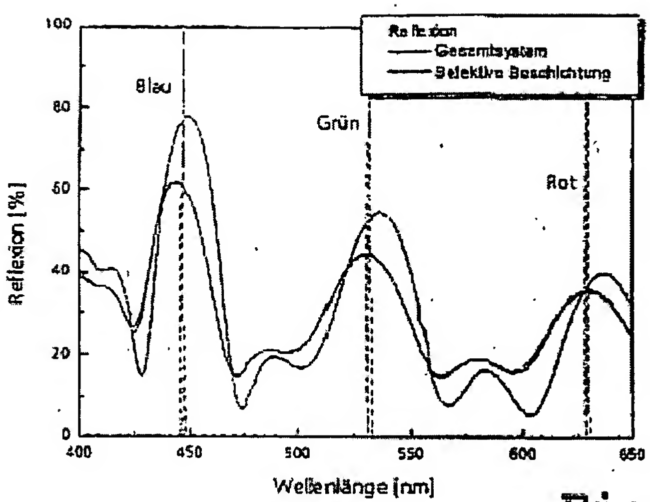


Fig. 2

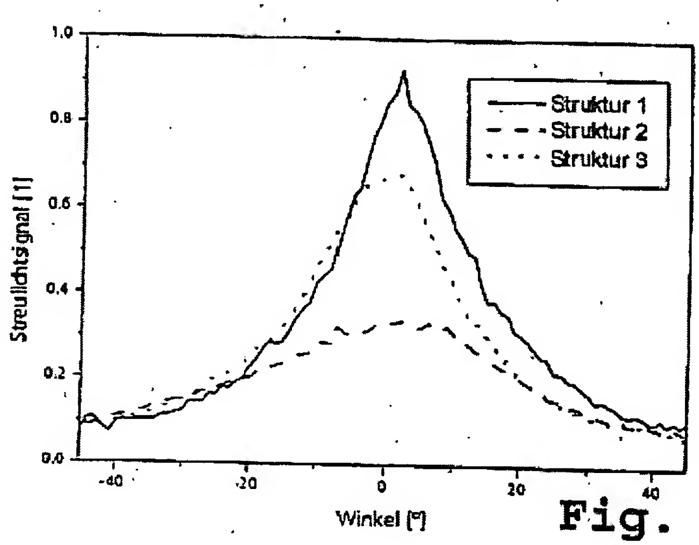


Fig. 3

[Reflektion = reflection]
[Gesamtsystem = total system]
[Selektive Beschichtung = selective coating]
[Wellenlänge = wavelength]
[Blau = blue]
[Grün = green]
[Rot = red]
[Struktur = structure]
[Streulichtsignal = scattered light signal]
[Winkel = angle]

Start

↓

Statistical population

↓

A: Recombination

↓

B: (Meta-)mutation

↓

C: Evaluation

↓

D: Selection

↓

No

Good capability? If no, go back to recombination

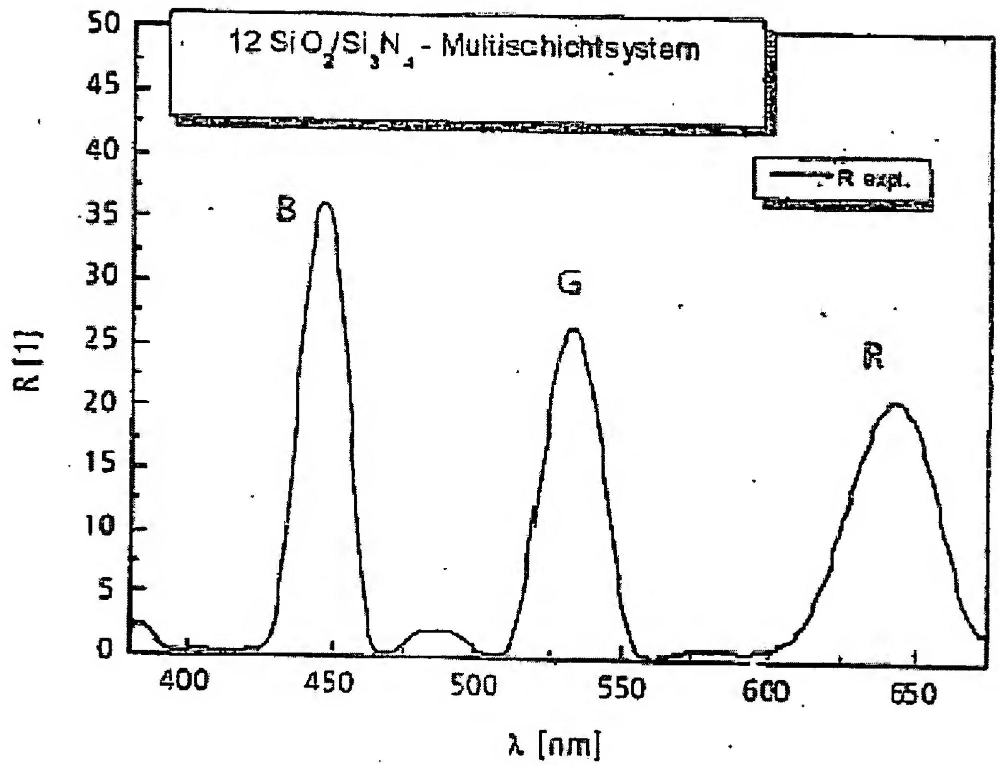
↓

Yes

↓

End

Fig. 4



[Multischichtsystem = multilayer system]